# A Formative Analysis of the Train Driving Task

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## Abstract

This paper presents a formative analysis of the train driving task. The train driving task is embedded in the railway domain which can be described as a complex sociotechnical system. These systems pose new demands on the analytical tools used in work analysis. The formative approach is thought to deal with these demands. The framework applied here draws on the Cognitive Work Analysis. It describes the task in terms of the behaviour shaping constraints embedded in five conceptual distinctions; work domain, control tasks, strategies, social-organisation and cooperation, and worker competencies. The focus is on describing the task in broad terms, and showing the interactions between the different conceptual distinctions, and how they shape the task. The study drew upon multiple data sources. Observations were made on two local traffic routes in Norway. Interviews with drivers and safety personnel, and studies of secondary data were also done. The framework applied here proved promising in showing how the train driving task is shaped through the constraints on the different levels. It also showed how the drivers deal with context-conditioned variability. It can, despite of problems with device-dependence and level of detail, provide a starting point for further studies. It can also provide a means of displaying data from formative analyses in other domains in order to demonstrate how constraints shape behaviour.



Keywords: rail human factors, formative analysis, train driving task.

# 1 Introduction

The rapid technological change the last fifty years has presented us with increasingly complex sociotechnical systems (Perrow, 1999; Vicente, 1999). Sociotechnical systems are systems which are composed of technical, psychological and social elements. They can be described as complex if rated highly on some of the following dimensions: large problem space, social, heterogeneous perspectives, distributed, dynamic, potentially high hazards, many coupled subsystems, automated, uncertain data, mediated action via computers, or disturbance management (Vicente, 1999; Woods, 1988). Well-known examples are industrial control centres, air traffic control, the bridge on a ship, emergency rooms, nuclear power plants etc. The complex sociotechnical systems represent progress in the way that they have given us the possibility to control and coordinate large forces and resources. There is at the same time potentially high hazards associated with the complexity of some of these systems and the impact of failure is more severe than with simpler systems. The increased risk and prevalence of accidents with catastrophic consequences are tell-tale signs of this (Casey, 1998; Perrow, 1999; Vicente, 1999). There is a need to increase our understanding of these systems in order to improve safety, productivity, and health. This is the rationale behind the research area of cognitive engineering, which is concerned with the analysis, design and evaluation of complex sociotechnical systems (Vicente, 1999; Woods & Hollnagel, 2006).

## *1.1 Railways as a complex sociotechnical system*

Wilson and Norris (2006; 2005) describe railways as a complex sociotechnical system. Many different stakeholders cooperate and act together with technology in order to run passengers and goods safely and efficient. It is also described as social as many different people are cooperating in many different subsystems. The different actors are also located in different places and the system can thus be described as distributed (Wilson et al. 2001) e.g. drivers, conductors, traffic control centre operators, maintenance, and station employees. Kecklund (2001) described the train driving task as being in an information vacuum which suggests uncertain data. The train system is also characterised by automated parts of the work (Kecklund, 2001; NSB AS, 2007). Railroads are commonly considered a safe transport domain (Wilson & Norris, 2006). The number of death caused by railway accidents in

Norway has been relatively steady for the last 30 years. In 2005 were 3 people seriously injured and 3 killed (Norwegian National Railway Administration, 2006). 997 people were in comparison seriously injured, and 224 were killed in traffic the same year (Statistics Norway, 2006). The “Åsta accident” in Norway and recent high profiled accidents like the Cumbria derailment in England 24th of February this year, and the train crash in France near the Luxembourg boarder the 11th of October 2006, has however contributed to an increased focus on rail safety. The rail domain is now, after years as a relatively slow changing domain, in the middle of a rapid technological change. Wilson and Norris (2006) predict that this trend will persist in the years to come as a result of heavier investments due to increased passenger load and environmental- and transport economical considerations. This is also true for the local traffic areas around Oslo, where new rolling stock is operating on the outer local route and the equipment on the inner local routes are due to be replaced within a five year period (NSB, personal communications, 2007).

## *1.2 Cognitive Engineering: New Demands on Analytical Frameworks*

The train driving task is embedded in the complex sociotechnical system of railways.  The study of work in these complex systems imposes new demands on how to study work, and it is important to find an analysis that takes this into consideration. Rasmussen (1997) makes a distinction between the normative, the descriptive and formative approaches to work analysis. This provides a useful taxonomy for comparing a number of different techniques with regards to the fundamental assumptions and problems of applying them to complex socio-technical systems. The discussion of these different techniques will follow this distinction.

## *1.3 Normative approach*

The normative approach divides the work into different tasks and subtasks, which describe the different steps needed to achieve a specified goal, and describe work in a “best way” manner. Tayloristic work methods, Goals, Operators, Methods and Selection rules model (GOMS) and task analysis are examples of this (Vicente, 1999). The use of these methods is prevalent in Human Factors (Sheperd & Marshall, 2005). A task analysis, is for example a detailed way of optimising the human element within a system in a systematically, open manner which can be subject to careful scrutiny (Kirwan & Ainsworth, 1992). The normative approach to work analysis is efficient because it identifies what needs to be done and how, and in this way provide us with a simple model of work (Vicente, 1999).

Railways have only recently obtained extensive attention from the human factors community (Wilson & Norris 2006). Traffic control centres is one of the areas, which has received a lot of attention in the rail domain. Published studies of the train driving task are, on the other hand, still relatively few but Hierarchical Task Analyses (HTA), of the train driving task has been done by Sheperd & Marshall (2005) and Rizzo, Pozzi, Save & Sujan (2005).

### *1.3.1 Evaluation of the Normative Approach*

The normative approach encounters despite their prevalence in human factors a few problems when applied to complex sociotechnical systems. The underlying assumptions of the normative approach are that the initial conditions are known, that influences can be accounted for and that goals can be clear stated (Vicente, 1999). Conditions need to be fixed in order to define a task (Leplat, 1989), and initial conditions are often unknown in complex sociotechnical systems. They are in addition subject to external influences, making them open systems. This means that there are patterns of disturbances in the system, which will rarely be repeated because it would require different types of action. This is referred to as context-conditioned variability, a term adopted from motor control literature (Vicente, 1999). The incapacity to specify the variance in the context causes a discrepancy between the task realised in context and the planned task (Gautherau & Hollnagel, 2005). Increasing complexity makes it more difficult to accurately predict tasks as well as dividing the task into subtasks (Leplat, 1994). Clearly identifiable goals are in addition not always possible to find, and in special circumstances associated with for example emergencies and accidents, can clear goals be hard to identify (Hollnagel, 2004). The normative approach will therefore suffer from some limitations when applied to the study of work in complex sociotechnical systems.

### *1.4 Descriptive Approach*

One of the main arguments towards the normative approach is that it does not portray work in a realistic way. The descriptive approach offers an alternative to this as it tries to "*describe how a system actually behaves in practice* "(Vicente, 1999, p. 61). It is descriptive in the way that it tries to document and understand current practices through field studies and naturalistic observation. Studies of situated action (Suchman, 1987), naturalistic decision making (Klein, 1995; Zsambok & Klein, 1997), activity theory (Bødker, 1991; Nardi, 1997), and distributed cognition (Hutchins, 1995) are all examples of descriptive approaches to work analysis (Vicente, 1999). The findings from the different descriptive approaches have two common themes. The first theme is the focus on the study of work in representative or naturalistic settings. The picture which emerges when studying work in situ and what workers actually do, is quite different from the one presented by the normative approaches. It shows how humans make things work in real life and draws a picture of workers as adaptive and ingenious in their everyday practices. The second theme, which appears in these studies, is the converging characterization of human work. They show; the importance of context conditioned variability, a strong social component, external mental processing in relation to the development and use of tools, time pressures, and that work is shaped by historical-cultural factors (Vicente, 1999). There have been few descriptive studies of the train driving task, but an example is a case study of the Italian railways in the investigation of distributed cognition (Eurocontrol, 2003).

### *1.4.1 Evaluation of the Descriptive approach*

The strength of the approach is how it portrays work as it is. Still, studies from social science, activity theory, francophone ergonomics and human factors show a weakness in relation to linking the findings to the design of new practises and artefacts. The fact that the work situation studied is representative of the actual work situation does not ensure relevance to intervention or design (Hoc, 2001). Design ideas are often based on the study of current practice (Vicente, 1999). A new artefact alters how work is done when it is introduced into a domain, and the result is new work practices. These practises are usually not adequately supported by the novelty and can result in new problems. Hence the new device meant to support the work actually transforms the work and presents entirely new challenges (Carroll, Kellogg & Rosson, 1991; Sarter &Woods, 2000; Dekker & Woods, 2002; Woods, 1998). This was e.g. seen in an evaluation of the 10 first years of the Automatic Train Control (ATC) system in Sweden, where the drivers altered their driving style to the ATC (Olhsson, 1990 as cited in Kecklund, 2001). The task-artefact cycle was introduced by Carroll et al. (1991) and depicts this interdependence between current practice and design and shows the circular nature of technological innovation. Thus the descriptive analysis is outdated the second we use it to alter an artefact or practice (Vicente, 1999).

## *1.5 Formative Approach*

The focus of the formative approach is *“identifying requirements- both technological and organisational- that needs to be satisfied if a device is going to support work efficiently”* (Vicente, 1999, p.61). The formative approach is concerned with modelling behaviour shaping constraints, defining constraints as relationships between, or limits on behaviour (Vicente, 1999). The idea is that human behaviour is governed by constraints, both associated with the system and within the human, and that these constraints must be respected for successful work performance (Rasmussen, 1990). The focus is on specifying the requirements rather than the prescribed steps associated with a task. This enables the formative approach to deal with the context-conditioned variability of complex sociotechnical systems. The formative approach strives to escape the task-artefact cycle by describing the task without referring to the existing technical solutions, also referred to as device-independence. This approach to work analysis can with this provide a solution to the problems associated with the normative and descriptive approaches (Rasmussen, 1997; Vicente, 1999). Finally, it is important to remember that the formative approach does not necessarily exclude normative or descriptive techniques (Vicente, 1999).

Rasmussen (1990; 1997) and Rasmussen, Pejtersen, & Schmidt (1990) suggest a version of a formative work analysis. Vicente (1999) elaborates this in his Cognitive Work Analysis (CWA). The CWA is a formative framework based on the analysis of work in terms of five conceptual distinctions, and this framework is used to model how constraints shape work. Each of the conceptual structures are further linked to a set of modelling tools and to different systems interventions, and the aim of the CWA is to develop new work practises (Vicente, 1999). This study will build on this approach and apply certain aspects of it.

There have not been many studies of the train driving task with a formative approach, but Jansson, Olsson & Erlandsson (2006) used the CWA to investigate the train driving task with the aim of improving the Automatic Train Control (ATC) interface. Biemans (2006) also used the CWA framework on train driving as a case study.

### *1.5.1 Applying the formative approach*

The formative approach deals with many of the challenges in the study of work in complex sociotechnical systems. The CWA is very resource demanding, and Vicente (1999) sees this as the main weakness of the approach. He does however open up for the possibility of focusing on a subset of the analysis in order to deal with specific problems. The Jansson et al. (2006) study is an example of this. They conducted a work domain analysis and the result was a redesign of the ATC interface. A focus on a specific problem and/or subset does imply sacrificing a more overall picture of the train driving task, and this can be problematic in two ways. First, the key in CE is to understand the various layers in the complex sociotechnical system and more important the interactions among them (Vicente, 1999). This means that it is valuable to strive to achieve a description of the train driving task in terms of all the various layers and their interactions. Second, the focus on specific problems entails other interesting features being overlooked. We believe that it is premature to decide such a specific problem or feature at this point, because we risk being fixed on the wrong problem.

The CWA will therefore not be used in its complete form. This study will focus on a broad perspective with a description of the various layers in the complex sociotechnical system and the interactions among them. We also hope to reduce the risk of overlooking important aspects by providing an overview of the train driving task.

### *1.6 The Formative Approach of this Study*

This study will use the conceptual distinctions as defined by the CWA (Vicente, 1999) and implement them into a framework developed for this study. The aim is to show how the constraints associated with the different conceptual distinctions shape the task, and the hierarchical interaction among the different levels. The framework will be described in the following.

The work domain is analysed first as it outlines the boundaries and the extent of the system being controlled. It is defined as "*the system being controlled, independent of any worker, automation, task, goal, or interface*" (Vicente, 1999, p.113). The next four conceptual distinctions are analysed together. The different control tasks pose different demands or constraints on the strategies chosen, which again affects the social organisation and cooperation, and finally the worker competencies required. It is these behaviour shaping constraints that the formative analysis strives to portray, and the four remaining conceptual distinctions will therefore be analysed together following the different control tasks.

The control tasks focuses on identifying what needs to be done, meaning the goals to be achieved. They can be defined as *"the goals that need to be achieved, independently of how they are to be achieved or by whom"* (Vicente, 1999, p.113). These goals can be differentiated in terms of being the overall goal or control task and more specific sub-tasks. Control tasks are separated into two categories because they represent slightly different levels of analysis.

Strategies are *"the generative mechanisms by which particular control tasks can be achieved, independently of who is executing them"* (Vicente, 1999, p.114). They are investigated next in relation to the defined control tasks. This conceptual distinction is also divided in two, according to different levels of analysis. The higher order strategies describes the strategies for action in general terms while the lower order strategies are closer to the strategies actually carried out by the system.

Social organisation and cooperation *"deals with the relationships between the actors, whether they be workers or automation"* (Vicente, 1999, p.114). This allocation of tasks and responsibilities is analysed in relation to their respective strategies.

Worker competencies are the *"constraints associated with the workers themselves"* (Vicente, 1999, p.114). The worker competencies in this study are analysed from the driver's point of view. We are therefore only referring to the drivers' competencies when commenting on worker competencies in this thesis. These are the human capabilities and limitations, and particular competencies, which need to be exhibited if they are to function efficiently (Vicente, 1999). We have in the analysis of worker competencies followed this division between human capabilities and competencies. Human capabilities point to the possibilities and limitations of human functioning. Competencies in this thesis will refer to more complex skills and knowledge acquired through learning. We have here further organised the competencies in terms of different types; technical competency (skills and knowledge concerning the train and the equipment), procedural competency (knowledge about the rules, routines and procedures), environmental competency (knowledge about the effect of weather conditions, the characteristics of the route etc.), and social competency (knowledge about the behaviour of passengers). Studies show that these competencies can be formal as learned through their education or more experience based (see e.g. Biemans, 2006; Kecklund, 2001), and we will also use this distinction.

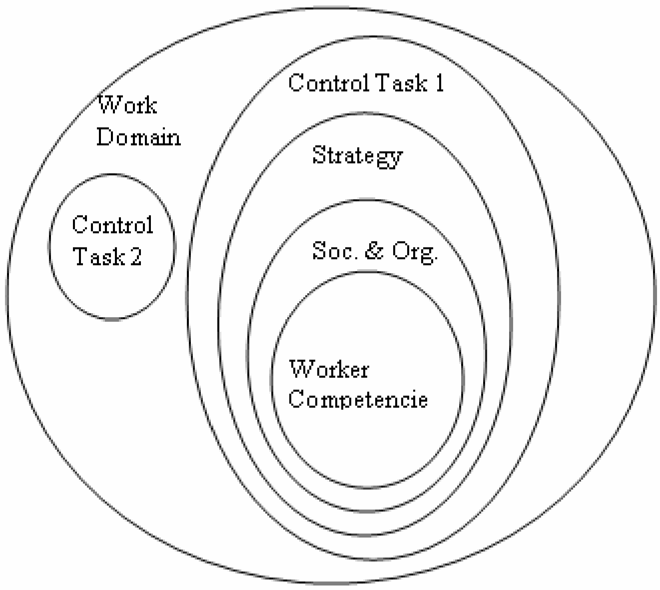


**Figure 1:** Nesting of the conceptual distinctions. Adapted from Vicente (1999) p. 116.

This study will use the formative analysis outlined above to investigate the train driving task. The CWA will not be used because it is either too resource demanding, or to narrow in scope, but the approach applied here is based on the conceptual distinctions of the CWA. The distinctions will be used with an emphasis on how the constraints in the different layers shape the task.

### *1.7 Aim of Study*

The starting point for Cognitive Engineering is the world of practice, demand for interventions, and tools (Maramas & Nathanel, 2005). The train driving task is embedded in a complex sociotechnical system of railways, which constitutes the world of practice for this study. The demand for intervention is due to the increased focus on rail safety and the rapid technological change in the domain (Wilson & Norris, 2006). The very characteristics of railways as a complex sociotechnical system also pose new demands on the tools we apply. The formative approach to work analysis described here provides a viable alternative to investigate the train driving task, and the first aim of the study is therefore:

1) To do a formative analysis of the train driving task and describe it in terms of the behaviour shaping constraints in the five conceptual distinctions.

Cognitive Engineering needs to refine its methods and models (Vicente, 1998). The version of a formative analysis suggested in this study borrows aspects from the established CWA (Vicente, 1999) and adds new ones. It is necessary to evaluate this study in order to assess the contribution to the field. The second aim of the study is therefore;

2) To evaluate the formative analysis framework applied in this study.

# 2 Methods

There is a need to draw on multiple methods when investigating complex sociotechnical systems (Hollnagel & Woods, 2005; Nardi, 1997; Vicente, 1999). The methods used in this study were observations, interviews and secondary data sources.

## *2.1 Observations*

The observations onboard were made on NSBs local routes during ordinary operations in February 2007. Two types of train types and routes were selected for this study. Both are local routes with a heavy load of passengers and many stops. The inner local route Skøyen - Ski has the highest frequency of stops of the two and is operated by the train type 69. They were produced in Norway between 1970 and 1993 but have been upgraded on newer safety equipment e.g. ATC and new telephone systems. The outer local route Spikkestad- Moss has fewer stops and is operated by the 72 train type, a newer model produced in Italy between 2002 and 2004.

The participants were 9 experienced train drivers who participated voluntarily. They were presented with information about the study and informed about their rights as participants before signing consent forms.

### *2.1.1 Direct observation*

The three direct observations were made in cab during normal operations with the 72 and 69 types with five different drivers. The observations were made both together with a safety official and alone with the drivers. The author had the opportunity to ask questions while out on the route. The observations were aided by a hand held DV-camera, notes and a photo-camera.

The cognitive walk-through technique was used during the direct observations (See eg. Kirwan & Ainsworth, 1992), and the train drivers were asked to comment on the actions they were performing while being filmed. This allowed for a view of both the non- observable and the observable actions that was taking place as well as providing an explanation of the procedures.

### *2.1.2 Indirect observation using video recording*

The direct observations were used to jump start the two indirect observations by providing information about how and where to place the video equipment. One trip with the 69 type and one with the 72 type was conducted with two different drivers on each trip. Two hand-held DV cameras were taped on the interior of the train cab. They were positioned to show the actions of the driver and the route ahead. The camera directed at the driver was equipped with a wide-angle lens in order to get a view of the whole in cab environment. The two perspectives were later synchronised and merged into a single screen allowing for the analysis of the drivers actions in relation to the environment outside the train.

### *2.1.3 Operational Sequence Diagrams*

The video material from the indirect observations were analysed by means of a task analysis. The analysis chosen was an Operational Sequence Diagram (OSD), which shows the sequence of control movements and information collective activities involved in a task. This type of analysis can be conducted in several ways and the type chosen here was a partitioned OSD, which focuses on specific criteria (Kirwan & Ainsworth, 1992). The criteria investigated here was the operations associated with a station area (approaching and leaving) and being on the line between stations. These criteria's were based on the direct observations. (For a sample of two OSDs from a station areas see Appendix 1). The direct observations and the interviews also informed the development of the OSDs.

### *2.2 Interviews*

Interviews were used throughout the study during the direct observation and separately. Both safety officials and train drivers were interviewed using unstructured interviews in the initial phases. In later phases three semi-structured interviews were conducted. The participants were train drivers with an average of 22 years of experience. The aim was to tap into the train drives own stories about the different challenges associated with their work as train drivers. They were also encouraged to elaborate on specific episodes were they had been particularly challenged or been under a lot of stress.

### *2.3 Secondary Data Sources*

Several secondary data sources was used and incorporated in the analysis throughout. This included annual reports and official laws and regulations, which are publicly available at the Norwegian Railways Inspectorates web pages (FOR 2002-01-29 nr. 122; FOR 2002-01-29 nr. 123; FOR 2002-12-18 nr. 1678; FOR 2002-12-18 nr. 1679; FOR 2001-12-04 nr. 1335; FOR 2001- 12-04 nr. 1336). Publicly available annual reports from the Norwegian National Rail Administration (NNRA) and the Norwegian State Railways (NSB) in addition to internal documents from NSB such as technical and safety documents were also used. The Traffic Safety manual (NSB AS, Persontog drift, 2007), which includes rules, regulations, and procedures for the passenger traffic, was extensively used. Accident reports from the Norwegian Accident Investigation Board (AIBN) were also included in this study.

# 3 Results

The results will be described in terms of the five conceptual distinctions; work domain, control tasks, strategies, social organisation and cooperation, and worker competencies. The work domain (3.1) is presented first before the next four (3.2) are presented together to demonstrate how the constraints of the higher conceptual distinctions influence the lower ones.

## *3.1 Work Domain*

### *3.1.1 Stakeholders*

The Norwegian railway system is comprised of several organisations and stakeholders. The Norwegian Railway Inspectorate (NRI) is the control and supervisory authority for all of the stakeholders (NRI, n.d.). They are responsible for ensuring that rail traffic is operated safely and appropriately in the best interest of the different stakeholders. The NRI is also responsible for drawing up regulations, awarding licenses and approving infrastructure and rolling stock. The Norwegian National Railway Administration (NNRA) is responsible for the infrastructure. They control the traffic via their traffic control centres, and are responsible for the maintenance of tracks, signs, signals and stations. There are ten ordinary traffic operators including both cargo and passenger traffic (NNRA, n.d.). The biggest company of the passengers' traffic is the Norwegian State Railways (NSB) with 49 million travellers in 2006 (NSB, n.d.).

### *3.1.2 Infrastructure & traffic conditions*

The transportation of passengers is divided into different routes, and two local routes around the Oslo- area were investigated in our study. The Moss- Spikkestad route is an outer- local route with an estimated duration of 1 hour and 35 minutes with 21 stops, and the Ski- Kolbotn route is an inner-local route with an estimated duration of 40 minutes with 24 stops.

Both lines are operated on the same double tracks (one in each direction) as far as the Ski station. The inner local train heads back at this station while the outer local train continues to

Moss. The line is one of the most heavily trafficked lines in Norway as it is not only operated by local traffic but also by cargo and intercity trains in addition to being the way to Oslo for the international routes from the continent via Sweden. The Norwegian National Railway Administration and their traffic control centre in Oslo are responsible for the control of traffic and they do this by controlling the traffic lights along the tracks (from now referred to as the signal system).

#### *3.1.3 Weather*

The weather influences the system by altering the trains driving performance and the drivers' conditions for observation. Ice can make the platforms slippery during the winter, and snow can impair the drivers view. Cold weather can also affect the power of the brakes and this has especially been a problem for the 72 types. The winter in Norway is characterised by shorter and darker days. The darkness increase the visibility of the signals, but it also decreases the visibility of disturbances along the line like people and animals. The problem is quite reversed during the summer season. The bright sunshine can make the light signals more difficult to see. Wet leaves a problem in the fall because they make the tracks very slippery and impair breaking.

### *3.2 Control Tasks, Strategies, Social Organisation and Cooperation, and Worker Competencies*

The constraints related to the four last conceptual distinctions will be presented together in this section. The control tasks are divided into overall task and sub-tasks. This is also the case for strategies, which is divided into higher order strategies and lower order strategies. Social organisation and cooperation is kept as a single category. Worker competencies are described as reflecting both human capabilities and competencies. Human capabilities reflect the possibilities and limitations of human functioning, while competencies points to more complex skills acquired either through formal education or experience.

#### *3.2.1 Overall Task and Presentation of Results*

The overall task or goal of the local traffic is to *safely, efficiently and comfortably transport passengers from a-b on time*. This overall goal can further be broken down to these three sub tasks; 3.2.2) *travel between stations in order to reach stations on time* (on the line). 3.2.3) *stop at station to let people on/off* (approaching station), and 3.2.4) *leave station on time* (leaving station). These subtasks are related to the different phases of driving found in our study. The order of the presentation of these sub-tasks does not reflect any difference in significance.

Each sub-task will be described independently in terms of strategies, social organisation and cooperation, and worker competencies. The emphasis is on how the different layers affect each other and this is achieved by describing the subtasks horizontally. The structure of the results is shown in Table 1.

| Control Tasks | | Strategies | | Sos. and Org | Worker Competencies |
|---|---|---|---|---|---|
| Overall Task | Sub-Task | Higher order strategies | Lower order strategies | | |
| | 3.2.2 On the line | → | → | → | → |
| | 3.2.3 Approaching station | → | → | → | → |
| | 3.2.4 Leaving station | → | → | → | → |

**Table 1: Organisation of conceptual distinctions in the analysis**

A practical reading guide for the following section is to take a brief look at the tables before and after reading the details of the different sub-tasks.

### *3.2.2 Out on the line*

The first sub-task we describe is to safely, comfortably, and efficiently travel between the stations in order to reach the stations on time. This can further be divided into three higher order strategies. These are; 1) keep the right speed, 2) maintain safety for people and equipment, and 3) make sure equipment works adequately.

For an overview see Table 2 at page 21.

*1) Keep the Right Speed*

*Higher order strategy*

To keep the right speed in relation to safety, the timetable, economic consideration and comfort is the first higher order strategy presented here. This is important in order to reach the stations in time and not cause delays on a heavily trafficked line.

*Lower order strategies*

The lower order strategy is to monitor the speed, and adjust it in relation to a number of factors; the timetable, the weather, traffic, technical status, and disturbances on the tracks.

*Social- organisation and cooperation*

There are several actors on the level of social organisation and cooperation. The signals, signs and speedometer are together with the Automatic Train Control (ATC) the main instruments to maintain the speed within the safety limits. The ATC system was developed to secure that trains do not pass stop signals, a situation called signals passed at danger (SPAD). The ATC will first give an auditive warning, then if necessary break and stop if the train is on the way of passing a stop signal. It also helps the driver keep the right speed by calculating the trains breaking curve. The Norwegian railways do not have full ATC coverage. One differentiates between areas without ATC, Full Automatic Train Control (FATC), and Partial Automatic Train Control (DATC). The maximum speed in FATC areas is kept under surveillance at all times, in contrast to areas with DATC where only the signals from the main signals and the pre-signals are controlled. This means that the ATC in FATC areas provides the driver information about the current speed and the target speed, while in the DATC areas only serves as a safeguard against SPADs. There are both areas with FATC and DATC on the routes of our investigation, and these are marked with signs to inform the drivers about the change in coverage. This difference in coverage means that task allocation between the driver and the ATC in terms of speed maintenance and stop signals is not static during the travel between stations.

Speed is also adjusted in accordance to the route book, which shows the driver the stations on the route and the departure time for each station on the route. The watch is together with the route book important in determining what the right speed is, because an increase in speed can mend things if the train is a little behind schedule. The drivers are in addition to keeping the timetable required to take economical considerations into their driving as well. It is for example uneconomical to drive fast if this only results in being to early at a station.

The traffic control centre is more directly involved in the case of special incidents in the traffic, or in the more common case of faulty signals. Every train is equipped with a phone to the traffic control centre, and the drivers are contacted in case of signal error or traffic incidents. The drivers can also contact the traffic control centre, and this is common in the case of faulty signals. They are required to contact the control centre when they get a stop signal for too long, and this procedure is specified in the Traffic Safety manual. The train can pass a stop signal with the permission of the traffic control centre, and this is done in order to keep the traffic flow. The other actors involved in speed regulation like the ATC, the signs, and the signal systems are fixed, and do not take weather and technical status into consideration, and these are the drivers' duties.

*Worker competencies*

Technical, procedural, and environmental competencies are important at the level of worker competencies. The mere act of regulating speed is a skill acquired during their education. To know how to regulate speed safely and efficiently entails the knowledge of how to incorporate the procedural knowledge from education, rules, and regulation with the experience-based knowledge about the environmental conditions and technical status.

*2) Maintain Safety for People and Equipment*

*Higher order strategy*

The second higher order strategy is to keep people and equipment safe. People and artefacts can enter the tracks and lead to dangerous situations.

*Lower order strategies*

The lower order strategies are to monitor the tracks and the environment for disturbances, and be prepared to break.

*Social -organisation and cooperation*

The allocations of tasks are by a mixture of people and artefacts. The signals and signs, and the ATC are instrumental in securing that no other trains are in conflicting positions. This task allocation actually changes as the train drives through areas with either FATC or DATC.  The driver also has to monitor the environment for other disturbances on the tracks. The “safety break system” (SIFA) is an automatic system which aim is to secure that the driver is alert and awake. It makes a sound with regular intervals, and stops the train if the driver does not respond to the sound by stepping on a pedal. In case of disturbances on the tracks are the only alternatives of action to stop and/or try to signal. The train’s long breaking distance does not allow rapid stops, so the driver has to detect the disturbance early in order to avoid impact. This means that the driver needs to be prepared to brake at all times, but an auditory signal (horn) is often the only real alternative. The standard procedure is to both break and use the horn. Especially risky places are equipped with signs that tell the driver to give the auditory warning “train is coming”. The social- and organisation and cooperation is characterised by the involvement of many actors. It also shows that there are limited means available to prevent impact with objects or persons while on the route.

*Worker competencies*

The human capability relevant here is first of all attention. The trains high speed and slow response time makes the driver’s response time more important. The driver also needs to be aware of whether s/he is in a FATC or a DATC area, since this change their task. The procedures and rules associated with this task are present in their formal procedural competencies. The drivers’ environmental competencies are also relevant, and it can be knowledge about especially risky places, bad weather conditions, risky times of day, and time of year. Examples are; a school nearby that increases the amount of kids on the platform, snow in the winter, Friday nights with people on the way from a party, or springtime with more tractors near the tracks.

*3) Make Sure Equipment Works Adequately*

*Higher order strategy*

The last higher order strategy associated with the subtask of being on the line is to make sure that the train/equipment works adequately.

*Lower order strategy*

This is done by the lower order strategy of monitoring the equipment in- and out-cab, and this strategy can be found in all of the three sub-tasks.

*Social -organisation and cooperation*

The social organisation and cooperation is distributed between the driver and equipment. Lamps and the IDU screen monitor the condition of the various parts of the technical system on the train. The IDU screen is a touch screen linked to a computer which monitors the status of the train at all times, and is used to diagnose the problem in case of deviations (Deviations, is a translation of the Norwegian term, used by the train personnel, for all deviations from the prescribed condition). The IDU screen is present in the newer trains like the 72, but not in the 69. The task of diagnosing error is in the 69 divided between the lamps in cab and the driver. The driver must, in case of a problem, physically walk around in the train and check. All trains are equipped with phones connected to a technical backup centre called DROPS. The drivers can contact DROPS if they need additional assistance in solving technical problems.

*Worker competencies*

The worker competencies associated with this lower order strategy are important. The driver needs extensive technical knowledge of how the train works and this is provided by their education. Experience also gives them schemas of what can be wrong and how to fix it. The information from the sounds, vibrations and mirrors, can be valuable for the experienced driver in assessing the technical condition. The tight schedule on the local routes makes this task of fixing technical errors important for the overall traffic conditions. It is the drivers' responsibility to resolve this fast if errors occur. All the drivers reported that the 69 and 72 trains were regularity haunted by errors. Especially the new 72 type was reported to need a lot of attention, and even the error-aiding IDU screen contribute to this by reporting non-existent errors on a regular basis.

| Control Tasks | | Strategies | | Sos. and Org | Worker Competencies |
|---|---|---|---|---|---|
| **Overall Task** | **Sub-Task** | **Higher order strategies** | **Lower order strategies** | | |
| Safely, efficiently, and comfortably transport passengers from a-b on time | Safely, comfortably, efficiently travel between the stations in order to reach the stations on time. | 1) Keep right speed<br>-safety<br>-timetable<br>-economic considerations<br>-comfort | Monitor speed and adjust according to<br>- signals and sings<br>- timetable<br>- weather<br>- traffic<br>- technical status<br>- disturbances on the tracks | Driver<br>Signals/signs<br>ATC<br>Route book<br>Train<br>Speedometer<br>Phones:<br>- Traffic Control Centre | Human capabilities<br>- Attention<br>Competencies<br>- Technical<br>- Procedural<br>- Environmental |
| | | 2) Maintain safety for people/equipment | Monitor, tracks and the environment for disturbances.<br><br>Be prepared to brake or signal | Driver<br>Mirror<br>Signals & Signs<br>Horn | Human capabilities<br>- Attention<br>Competencies<br>- Technical<br>- Procedural<br>- Environmental<br>- Social |
| | | 3) Make sure train/equipment works adequately | Monitor train/equipment | Driver<br>IDU<br>Lamps<br>Mirrors | Human capabilities<br>- Attention<br>Competencies<br>- Technical<br>- Procedural<br>- Environmental |

**Table 2: On the line**; the sub-task of safely, comfortably, efficiently travel between the stations

### *3.2.3 Approaching station*

The sub-task of safely, comfortably, efficiently stop at station to let people on/off can be described into seven higher order strategies. These are; 1) Detect the right station, 2) Inform passengers about the next station, 3) Maintain safety for people and equipment, 4) Stop smoothly and safely, 5) Maintain safety for people on station, 6) Let people on and off, 7) Make sure that train/ equipment is functioning adequately.

For an overview see table 3 and 4 at pages 28 and 29.

*1) Detect the right station*

*Higher order strategy*

The first higher order strategy is to detect the right station, and is important because the train does not always stop at each station.

*Lower order strategies*

To monitor the environment, both in-cab and out cab is the lower order strategy associated with detecting the right station.

*Social- organisation and cooperation*

The social organisation and cooperation divides this between the driver and other artefacts. The Route book is a book that shows the driver all the stations on the route and the departure time for each station. Signs along the tracks also inform that a station is coming, and this task is further supported by the automatic station announcer in the 72 trains further supports this task. This is GPS controlled and is although primarily aimed at the passengers also heard by the driver.

*Worker competencies*

The human capabilities needed to fulfil these strategies are attention to the information presented. The competencies required are the procedural knowledge from their education in the meaning of signs and signals. The experienced drivers do however report that they know the route so well that they at all times know which station is next. This emphasises the importance of the informal competencies acquired through experience. Their primary source of information for these informal competencies is then in the environment, meaning the different topographic features along the track.

*2) Inform passengers about the next station*

*Higher order strategy*

The next higher order strategy is to inform the passengers of the next station, so they can get off at the right station fast and efficiently. Rapid stops at each station are required to keep the timetable.

*Lower order strategies*

The lower order strategy here is to announce the next station for the passengers.

*Social- organisation and cooperation*

The social organisation and cooperation is differently solved at the two train types. The automatic station announcer responsible for this in the 72, and the information is also available on a digital display in the passenger carriages. The drivers announce the stations, trough the speaker system in the 69.

*Worker competencies*

The workers competencies needed here is to know these procedures so well that they are able to perform them while driving. What to say is specified in the Traffic Safety manual and is a part of their formal education.

*3) Maintain Safety for People and Equipment*

*Higher order strategy*

Maintain safety for the train and the people along the tracks is a higher order strategy associated with the sub task of approaching a station. It is also found in the other two sub tasks.

*Lower order strategies*

The lower order strategies are to monitor the tracks, and the environment for disturbances and to be prepared to break.  These lower order strategies are also found in the two other sub tasks. To make sure that the station is clear of other trains distinctive for the sub task of approaching a station. The following description will only describe this, as the other already has been described at page 18.

*Social- organisation and cooperation*

The signal system is responsible that the station is clear to enter. The ATC aids in helping the driver not pass this signal, and the traffic control centre aids in case of malfunctions.

*Worker competencies*

The human capabilities required here is attention. The drivers' procedural and environmental competencies are in addition important. The procedural competencies, both formal and informal, are to know what to do in the case of malfunctions. The environmental competencies are more informal and are concerned with; where the signals are, if they can expect a stop sign etc.

*4) Stop smoothly and safely*

*Higher order strategy*

To stop the train smoothly and safely is another higher order strategy. Most of the drivers told that they invest quite a lot in making the train go as smoothly as possible to increase passenger comfort. To not approach the station too fast is also a key ingredient in stopping the train safely.

*Lower order strategies*

This is a gradual decrease in speed is necessary when approaching a station. However, this decrease needs to be balanced to the demands of the timetable, because a premature decrease in speed can cause delays.

*Social- organisation and cooperation*

Here are the drivers the most important actor. The train is responsible for the actual decrease in speed, and the speedometer gives information about the changes in speed, but it is the drivers who execute the task.

*Worker competencies*

This is an area where worker competencies and especially experience is crucial. Stopping a train smoothly and safely is dependent on experience. There are many factors affecting the process that needs to be balanced. The knowing effect of the brakes is one example, and this information is available for the drivers in the technical report, which follows every train. They also know the breaking length associated with the particular train type. The weather also affects the breaking curve of the train. All off these factors are a part of the calculation the drivers are required to do in order to stop smoothly. This demonstrates the procedural, environmental and technical competencies needed. Many of the drivers also report this competency as something that separates the good drivers from the bad.

*5) Maintain safety for people on station*

*Higher order strategy*

The next higher order strategy is to maintain safety for the people on the station. The station area is an area with a lot of people near the tracks. Driving into a station and letting people on and off requires an increased focus on the safety for these people.

*Lower order strategies*

To monitor the behaviour of the people on the station is the lower order strategy here.

*Social- organisation and cooperation*

The social organisation and cooperation for this higher order strategy is here divided between the driver, artefacts and the conductor. The conductor we refer to here is a conductor with a safety clearance that is responsible for the safety of the passengers, and the Norwegian term is “onboard responsible”. Here we will only refer to them as conductors. Both train types are required to have this kind of conductor on board. The driver and the conductor collaborate to maintain the safety for the passengers as well as the people on the station. This allocation of responsibilities and cooperation is described in the procedures.  They are in addition required to brief each other on important information on every trip or work shift. The driver is responsible for the people on the station as long as the doors have not been opened. S/he monitors the station both forwards, and backwards in the mirror while approaching. The drivers are at some stations required to signal “train is coming” with the horn before entering the station area. A sign marks this by the tracks. Some times the driver also warns people with the horn if they are close to the gap at the station. After the train has stopped and the doors are open is it the conductor-guard that has the main responsibility for the people on the station. The driver still maintains an eye on the situation in the mirror.

*Worker competencies*

Attention is again crucial. The drivers draw on the procedural competencies from education and the social and environmental competencies from experience. E.g. certain people display more risk behaviour like children, adolescents or passengers with a high alcohol intake. This makes the drivers extra cautious on stations with schools nearby or in the weekends.  The weather also plays a part and can for instance make the platform slippery.

*6) Let people on and off*

*Higher order strategy*

Let people on and off is a higher order strategy realised through several lower order strategies.

*Lower order strategies*

The doors need to be opened followed by an announcement, and the process needs to be monitored.

*Social- organisation and cooperation*

The driver opens the doors and announces that the doors are opening. In the 72 the automatic announcement system is responsible for the announcement. The process is monitored by the driver in the mirrors, and by the conductor on the platform. It is the conductor that has the main responsibility for looking after the passengers when letting people on and off. In the 72 the driver can also check the IDU screen for information about the doors, but our observations show that they seldom look at the screen at this point.

*Worker competencies*

The driver needs to be attentive, and know the procedures of how to open the doors and what his/her responsibility is. The driver also benefits from experience when it comes to e.g. environmental competencies like a slippery platform and social competencies like small children's behaviour.

### 7) *Make Sure Equipment Works Adequately*

*Higher order strategy*

The last higher order strategy associated with the subtask of approaching the station is to make sure that the train/equipment works adequately.

*Lower order strategy*

This is done by the lower order strategy of monitoring the equipment in- and out-cab, and this strategy can be found in all of the three sub-tasks. However, examples of equipment especially relevant for this particular subtask are the brakes, the doors, and the automatic announcement system. The latter can announce the stations at the wrong time. The driver is in this case required to detect this, turn it off, and take over. The following description will only follow the strategies particular for this sub task, as the others already has been described at page 19.

*Social- organisation and cooperation*

The driver has the main responsibility here. S/he has to check that what the announcement system is announcing the right stations. The IDU screen assists in monitoring the technical system, and it also has a function that shows the status of the doors.

*Worker competencies*

The worker competencies here are technical, procedural, and environmental competencies. They are thoroughly described at page 20.

| Control Tasks | | Strategies | | Sos. and Org | Worker Competencies |
|---|---|---|---|---|---|
| Overall Task | Sub-Task | Higher order strategies | Lower order strategies | | |
| Safely, efficiently, and comfortably transport passengers from a-b on time | Safely, comfortably, efficiently stop at station to let people on/off. | 1) Detect right station | Monitor the environment | Driver<br>Route book<br>Signal/Signs<br>Automatic station announcer (72), | Human capabilities<br>- Attention<br>Competencies<br>- Procedural<br>- Environmental |
| | | 2) Inform costumers about station | Announce the next station | Driver Automatic station announcer (72)<br>Speaker (69)<br>In cab text-sign (72) | Competencies<br>- Procedural |
| | | 3) Maintain safety for people/equipment on tracks | Monitor out cab environment. Makes sure that the station can be entered. Signal to others if danger. | Driver<br>Horn<br>Signals/signs<br>Mirrors<br>ATC<br>Train | Human capabilities<br>- Attention<br>Competencies<br>- Procedural<br>- Environmental |
| | | 4) Stop smoothly and safely at the right time. | Adjust the speed by decreasing speed and breaking. | Driver<br>Train<br>Speedometer<br>Signal/Signs | Competencies<br>- Technical<br>- Procedural<br>- Environmental |

**Table 3: Approaching station**; the sub-task of safely, comfortably, efficiently stop at station to let people on/off

| Control Tasks | | Strategies | | Sos. and Org | Worker Competencies |
|---|---|---|---|---|---|
| Overall Task | Sub-Task | Higher order strategies | Lower order strategies | | |
| | | 5) Maintain safety for people on station | Monitors the behaviour of people on the station. Looks to control backwards. Signal before approaching certain stations | Driver<br>Mirrors<br>Horn<br>Brakes<br>Conductor<br>Signs | Human capabilities<br>- Attention<br>Competencies<br>- Procedural<br>- Environmental<br>- Social |
| | | 6) Let people on on/off | Opens doors, and announces this. Monitors the process | Driver<br>Automatic announcer<br>Conductor<br>IDU | Human capabilities<br>- Attention<br>Competencies<br>- Procedural<br>- Environmental |
| | | 7) Make sure train/equipment works adequately | Monitors the train/equipment, in cab and out cab. | Lamps<br>Driver<br>IDU<br>Mirrors<br>DROPS | Human capabilities<br>- Attention<br>Competencies<br>- Technical<br>- Procedural<br>- Environmental |

**Table 4: Approaching station** (cont.); the sub-task of safely, comfortably, efficiently stop at station to let people on/off

### 3.2.4 Leaving a Station

The subtask of safely comfortable and efficiently leave station on time can be described in five higher order strategies. These are; 1) Maintain safety for people on station, 2) Leave station on time, 3) Reach travel speed fast, 4) Maintain safety for people/equipment on tracks, 5) Make sure train/equipment works adequately. For an overview see table 5 and 6 p. XX

*1) Maintain safety for people on station*

*Higher order strategy*

The next higher order strategy is to maintain safety for the people on the station while leaving the station.

*Lower order strategies*

To monitor the behaviour of the people on the station is the lower order strategy here. Both areas backwards and forwards are important to watch.

*Social- organisation and cooperation*

This is primarily the conductors' task when the doors are open, and the drivers only contribute by monitoring the mirrors. However, the drivers have the sole responsibility as soon as the doors are closed.

*Worker competencies*

The main human capability relevant here is attention. The drivers also need to have environmental competencies like knowledge about slippery platforms. Social competencies like knowledge about people's behaviour can be important as well.

*2) Leave station on time*

*Higher order strategy*

Leave station on time is the second higher order strategy when leaving a station, and is important in order to keep the schedule. Two aspects of this higher order strategy is especially safety critical; that the train only leaves when it is safe to leave, and that the passengers entering the train are safe.

*Lower order strategies*

Leaving a station on time involves a sequence of five lower order strategies. First, it is necessary to find out whether it is safe to leave the station (i.e. that there are no other trains on the tracks ahead). Second, it is important to make sure that the passengers are safe. Third, the doors need to be closed. Fourth, the train is ideally required to leave the station on the second. Finally, the train must accelerate as fast, comfortably, and safe, as possible.

*Social- organisation and cooperation*

The allocation of the strategies seen above, are distributed between the driver, the conductor-guard, the signal system, the IDU screen, mirrors, the train, the route book, and the clock. The departure routine describes the organisation of these actors.

First, the information about when it is safe to leave the station is obtained through the signal system and it is up to the driver to collect this information. The driver communicates the permission granted signal to the conductors via a lamp outside the train. The conductors double-check this information.  Second, it is the conductors who decide when the train can leave, and they signal this to the driver with a flag or lamp. Their responsibility is to make sure; that the passengers are safe, that they have a permission to leave, and that they leave on time. Third, the drivers can close the doors when the conductors have signalled that they are ready to leave.  The drivers in the 69s watch the doors close in the mirror, while the IDU screen in addition aids the drivers in the 72s.  The doors in the 72s are actually closed two times. This is because all the doors are closed except the conductor's door.  The conductor needs to see that everything is ok before going inside and close their door. The driver is next required to lock the door. A speaker message informs the passengers that the doors are closing in order to ensure the passengers safety. The automatic announcement system is in charge of this in the 72s. Fourth, the conductor checks their watch before they give their signal to leave. The driver needs to check the clock against the route book to ensure that the train leaves on time. The drivers on the inner-local route (69) report that their tight schedule often makes checking the time redundant because it is all about doing things as fast as possible anyway. Finally, the driver has to start the acceleration and monitor the platform area.

*Worker competencies*

This sequence entails large number worker competencies. The human capability most salient here is attention. The competencies required are procedural, technical, environmental, and social. The formal technical knowledge is connected to getting the train to move and operate the other equipment. The procedural knowledge is concerned with the procedures associated with leaving a station safely, and these are both formal and informal. The environmental knowledge is associated with characteristics of the station, the weather and the traffic. The social knowledge is associated with the characteristics of the conductor-guard and the behaviour of the passengers entering the train.

*3) Reach travel speed fast*

*Higher order strategy*

Reach travel speed fast is the third higher order strategy of leaving a station. This is instrumental in keeping the tight schedule.

*Lower order strategies*

The lower order strategy is to accelerate as fast as possible, in a safe and comfortable manner.

*Social- organisation and cooperation*

The signal system sets the maximum allowed speed, but the drivers are responsible for the actual execution of lower order strategy of accelerating as fast as possible.

*Worker competencies*

The human capability most involved in reaching travel speed fast is attention. The procedural competencies associated with driving the train are also important. This part of the task is a part of their formal education in rules and procedures. Their informal knowledge involves knowing how to operate the train as efficiently and smoothly as possible. The environmental competencies include incorporating information about the weather, the trains technical status, and features of the line.

*4) Maintain safety for people on the station*

*Higher order strategy*

The next higher order strategy is to maintain safety for people/equipment on the station while leaving the station.

*Lower order strategies*

To monitor the tracks and the environment for disturbances both forwards and backwards is the lower order strategy applied when leaving the station.

*Social- organisation and cooperation*

The driver is the only one responsible for this.

*Worker competencies*

This type of monitoring task requires attentiveness from the driver. Social- and environmental competencies are at work here. That school kids are more risk taking, in crossing the tracks after getting off is an example of the social competencies. The environmental competencies are e.g. to know that the slippery station can make running latecomers fall into the tracks.

*5) Make sure train/equipment works adequately*

*Higher order strategy*

To make sure train/equipment functions adequately is the final higher order strategy for leaving a station.

*Lower order strategy*

This is done by the lower order strategy of monitoring the equipment in- and out-cab, and this strategy can be found in all of the three sub-tasks. Equipment especially relevant for this particular subtask is the doors, the engine, and the automatic announcement system. The following description will only follow the typical strategies for this sub task, as the others already has been described at page 19.

*Social- organisation and cooperation*

The drivers use the mirrors to see whether the doors have closed properly in the 69. In the 72 the IDU screen, which shows whether the doors are open, aids the drivers. The automatic announcement system gives information about the closing of the doors, and the drivers' need to check that the information is correct.

*Worker competencies*

The driver needs to be attentive and make sure that everything is as it should be. The competencies required are technical, and environmental. The technical competencies are informal as well as formal. An example is to know how the fast the train is supposed to accelerate under the given circumstances like e.g. slippery tracks.

| Control Tasks | | Strategies | | Sos. and Org | Worker Competencies |
|---|---|---|---|---|---|
| **Overall Task** | **Sub-Task** | **Higher order strategies** | **Lower order strategies** | | |
| Safely, efficiently, and comfortably transport passengers from a-b on time | Safely, comfortably, and efficiently leave station on time. | 1) Maintain safety for people on station | Monitor platform | Driver<br>Conductor/ guard | Human capabilities<br>- Attention<br>Competencies<br>- Environmental<br>- Social |
| | | 2)Leave station safely on time | Make sure that it is safe to leave<br>Make sure passengers are safe<br>Close doors<br>Start accelerate comfortably, safe and fast | Driver<br>Signals<br>Conductor<br>IDU<br>Train<br>Route book | Human capabilities<br>- Attention<br>Competencies<br>- Procedural<br>- Environmental<br>- Social |
| | | 3) Reach travel speed fast | Accelerate as fast as possible | Driver<br>Signals/Signs<br>Train | Human capabilities<br>- Attention<br>Competencies<br>- Procedural<br>- Environmental |

**Table 5: Leaving station**; the subtask of safely, comfortably, and efficiently leave station on time.

| Control Tasks | | Strategies | | Sos. and Org | Worker Competencies |
|---|---|---|---|---|---|
| Overall Task | Sub-Task | Higher order strategies | Lower order strategies | | |
| | | 4) Maintain safety for people/equipment on station | Monitor the tracks and the environment for disturbances.<br>Monitor the environment forward. | Driver<br>Mirrors<br>Conductor | Human capabilities<br>- Attention<br>Competencies<br>- Procedural<br>- Environmental<br>- Social |
| | | 5) Make sure train/equipment is functioning adequately | Monitor train/equipment | Driver<br>IDU<br>Lamps<br>Mirrors | Human capabilities<br>- Attention<br>Competencies<br>- Technical<br>- Environmental |

**Table 6: Leaving station** (cont.); the subtask of safely, comfortably, and efficiently leave station on time

# 4 Discussion

## *4.1 General Findings*

The results outline the many details of the train driving task. All the same, several features were also discovered. We presented the task in terms of the work domain, control tasks, strategies, social-cooperation and organisation, and worker competencies. The overall task of train driving is structured into relatively clearly defined sub tasks. Each of these subtasks shapes the strategies available, the social-organisation and cooperation, and the demands on the drivers. These general features will be discussed in the following section.

### *4.1.1 Task Transformation & Constraints*

The drivers work conditions are characterised by rapid change. The conditions are altered as they constantly move through the landscape and switches between the different phases or sub tasks of driving, and deal with the variability of the technical and organisational components. This is a feature shared with work in other transport systems (Petersen & Nilsen, 2001). The work domain set the frame for the task in question. In the analysis can this framing be seen when the different control tasks, strategies, social- cooperation and organisation, and worker competencies change as the work domain change. An illustration is the weather, which is a significant source of variability in Norway, and influences the train driving task in many ways. For example, the ability to keep the right speed (acceleration and deceleration) is subject to variation as snow, ice, and downfall, which affect friction. Less friction alters the trains breaking capabilities, and thus alters safe speed limits. This is something that must be incorporated into the lower order strategies. It also changes the social organisation- and cooperation as the drivers and not the signs then decide the maximum speed. It forces the driver to compensate for the mismatch between the fixed sign system and the variable weather.

The control tasks were described in terms of one overall task and the three sub tasks; 1) being out on the line, 2) approaching a station, and 3) leaving a station.  This three way split of the train driving task, has been found in other studies too (Brotnov, 2007; Kecklund, 2001; Jansson et al. 2006; Jansson, Olsson & Kecklund, 2000). The different sub tasks also shape the lower layers of the conceptual distinctions. For example, the higher order strategy of making sure the equipment is functioning adequately is important in all three sub-tasks. However, the driver monitors and pays attention to different parts of the system during each sub-task. This suggests that each sub-task is analytically as well as practically apart, in the sense that they structure the work situation for the driver.

The different strategies shape the lower level of social- organisation and cooperation by defining the control tasks involved and how they are to be allocated and coordinated. For example to monitor the speed, and calculate the breaking curve is a strategy divided between the ATC and the driver. Worker competencies are described last and workers deals with the constraints of all the five conceptual distinctions.

The results demonstrate how the general task can be broken down into concrete demands, through the structure borrowed from the CWA (Vicente, 1999). Similarly, Leplat (2000) argues that general tasks given to operators always are deconstructed down to concrete actions This means that the emphasis is not on how to execute the work task, but to adapt to, or accommodate the work task. He further argues that this task transformation is made in relation to how the workers understand the task. Nevertheless, the workers understanding of the task is not necessarily correct. Drivers were for example found to have a wrong picture of how the ATC works (Jansson et al. 2000). Dangerous situations or accidents can occur if these adaptations do not respect the constraints of the task (Christoffersen &Woods, 1999). Safety can then be thought of as respecting constraints (Vicente, 1999). Our CWA based study provides an overview of what the task is adapting to, namely the constraints. We have here showed how the constraints affect the drivers' possibilities of action. The formative analysis has in this sense worked as a frame of reference for task transformation.

### *4.1.2 The Drivers Role: Dealing with context-conditioned variability*

*"It is not our problem. I don't mean that it isn't our problem... It is not our fault, but it it's ours to fix."*

(A driver's reply to the many disturbances they must deal with in their work)

Two points can be made about the drivers' role in the train driving task. First, the train driving task is heavily constrained in terms of the physical space in the cab, the safety equipment, the many rules and regulations, and the many procedures. Almost every subtask and circumstance has been tried accounted for in the Train Safety manual. The drivers themselves describe their task as highly regulated. However, Leplat (1994) argues that every prescription of a task implies that the worker must compensate for the shortcomings. This brings us over to the second point. The analysis shows that the drivers on the local lines are dealing with a high degree of context-conditioned variability and the drivers need to adjust to the different constraints and change their actions in order to achieve the goals needed. The rationale for the presence of humans in work systems is both their ability to manipulate objects and tools in a flexible and versatile way as well as being adaptive problems solvers (Pejtersen, 1995). The timing and interpretation of the work situation precedes the actual actions chosen. The Train Safety manual does not formulate situation specific variance, and the drivers experience and expertise do to a large extent serve as a condition for implementation of safety measurements. An important value in the formative approach is to identify and support workers adaptive behaviour (Vicente, 1999). Three examples can be used to demonstrate how the drivers deal with the context-conditioned variability.

First, to stop smoothly is dependent on and constrained by several different factors. The driver applies the braking system to make the train come to a halt smoothly. The application of the braking system is used in coordination with a number of information resources: Signs informing the distance to the next station, topographical variations along the tracks, weather status, technical status of the train, and so forth. None of these information sources/conditions are sufficient in them selves to guide a specific station approach, but are used in combination to accommodate safety, efficiency and comfort.

Second, a significant source of the context-conditioned variability experienced by the drivers is failure in the technical equipment. Both the 69 and 72 types experience regular technical problems, and a failure on the heavily trafficked lines can lead to delays for a whole day. If a problem occurs are the drivers required to try to locate and fix the error. An example is when the automatic mode of the 69 does not work after turning at an end station. This is an easily solved and quite common error, which is caused by a plugged out fuse. The drivers then have to find the right fuse cabinet and push the fuse in. The drivers take great prides in successfully diagnose and/or mend a failure. The English synonym for drivers are train engineer and locomotive engineer, these titles emphasise the technical expertise required in this job. This example sheds lights on how the technical equipment both is a condition for solving the task and the focus of problem solving. This shows how the technology is not objective and stable, it is in it self a source of variability. The drivers are in other words required to drive, as well as making sure that the vehicle works.

Third, the signal system is responsible for the control of the traffic on the line and ensuring safe operations on a busy line. It is not allowed to pass a signal that displays the message "stop". A malfunctioning signal is programmed to stay in "stop" until the problem is fixed. This prevents the dangerous situations of "signals passed at danger "(SPADs) but can also halt the traffic flow and cause delays. Drivers who come across signal which have been "in stop" for too long are required to; call up the traffic control centre, get a permission to drive pass, reset the ATC, and continue. This is described in detail in the Traffic Safety manual, but the actual evaluation of what is "too long" is dependant on the drivers' knowledge about the route and the traffic that day. These examples show how the drivers deal with the context-conditioned variability and how the system is dependent on the drivers' adaptive actions in order to achieve its goal. They also point to the technical system as a source of variability in it self, which influences the allocation of tasks. This means that social- organisation and cooperation on the task is not only altered by strategies, control tasks and work domain, but also technology.

The formative approach is in contrast to the normative approach explicitly aimed at studying work characterized by context-conditioned variability, and so our findings support our choice of analysis.

### *4.1.3 Route Knowledge*

The drivers deal with the context conditioned variability when they drive the train. Their competencies enable them to handle these challenges. We divided the worker competencies into human capabilities and competencies (environmental, technical, procedural and social) in our analysis (Vicente, 1999). Another distinction we made was between formal and informal competencies. The formal competencies are of course a prerequisite for driving the train safely. However, the existence of extensive informal competencies acquired through experience is also important. A few examples can illustrate this. Choosing the right speed is a higher order strategy is dependent on the drivers' capacity to incorporate several factors. The formal competencies required here is associated with knowing the rules, regulations, and how to technically operate the train. The examples of the informal competencies they need are many: Knowledge about stations with school children, or where tractors are placed near the tracks is important for safety. Economic driving is dependant on knowing that the tracks go downhill in a few minutes, which makes an increase speed unnecessary. Comfortable driving is also increased when the driver knows that one should start decreasing speed when passing a specific rock.

Informal competence has also been investigated under the term "route knowledge", and is defined by being experience-based, gained from many types of information sources and required to operate safely and efficiently (Biemans, 2006). Swedish studies of the train driving task have also looked at route knowledge, describing it as a critical part of the drivers' operational knowledge base (Jansson et al. 2006; Jansson et al. 2000). Our use of the informal knowledge is more detailed than the broadly defined route knowledge. We specify whether the knowledge or competence is linked to the performance of a task (procedural), topography, features of the track, or weather (environmental), technical issues (technical), or to people's behaviour (social).

The importance of the drivers' route knowledge or informal competencies is supported by our findings. It also shows how the ability to deal with the demands of context-conditioned variability successful is closely linked to experience-based competencies.

### *4.2 Evaluation of the Formative Approach*

This application of the formative approach on the train driving task was useful as it provided an overview of the task. It suggested how the constraints associated with the higher conceptual distinctions shaped the lower ones, and ultimately the task as a whole. How the train driving task is characterised with context conditioned variability was found too. The importance of informal competencies was also emphasised. Some difficulties with applying the approach were however encountered, and these will be discussed below.

### *4.2.1 Device-dependence*

A clear stated goal of the formative analysis is to avoid the task artefact cycle. This is solved in the CWA by describing the task without referring to the existing technical solutions aiding the work. The analysis tries in other words to avoid device-dependence (Vicente, 1999). The definitions of the conceptual distinctions clearly state that the work domain, control tasks, and strategies should be referred to without mentioning any technical solution. It is in the description of the social-organisation and cooperation that these features of the system belong.

It nevertheless proved difficult to describe the work domain, control tasks, and strategies without referring to the technical solutions. This problem could be due to the fact that train driving is inherently device dependant (i.e. the train), and that the very premise of describing parts of the task without referring to the device therefore is difficult. Train driving is a task aided by automation and this posed a problem in the analysis. This is seen as the analysis is characterised by the occasional jump in the level of analysis and one example is how the drivers keep the right speed with the help from the ATC. This solution affects the drivers lower order strategy of keeping the right speed, and to exclude this in the presentation of these strategies would make the analysis incomplete. The description of the ATC belongs conceptually at the next level namely the social- organisation and cooperation and this is in this manner not consistent with the definitions in the analysis.

Lind (2003) discusses the problems associated with analysing a system independent of automation. He argues that the CWAs (Vicente, 1999) definition and modelling of the conceptual distinctions as independent of the automated systems makes an artificial distinction between systems with and without automated technical solutions. The implication of this is that the modelling of conceptual distinctions cannot be used in interface design in systems with automated control devices.  To exclude these devices in our analysis would thus decrease the value of the study in terms of design implications, which is a clear stated goal of the formative analysis. Lind (2003) further states that it is important that Cognitive Engineering meets the needs of the real world, and that a design methodology should be applicable even though total device-independence is not possible. Burns (2004) also found the device-independence difficult to achieve in their work domain analysis. Their article further states that it can be important to include the state of the automated system in relation to other components, into the analysis. They suggest dual models where one takes the automated system into consideration, and the other is without.

We argued earlier that the main weakness of the descriptive approach is the device dependence. The description of the task presented in this thesis is device-dependent. This is a serious flaw because one of the arguments of doing a formative analysis is the normative and descriptive approaches inability to escape the task-artefact cycle. It can thus be argued that this study actually is descriptive rather than formative. However, even Vicente (1999) accepts to a certain degree that the description of a task is descriptive, what makes an approach formative is the modelling of the behaviour shaping constraints (see Figure 2). This study describes the behaviour shaping constraints, and provides an overview of usable for further modelling.

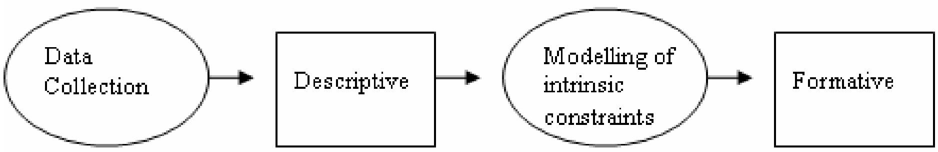


**Figure 2**: The relation between the descriptive and the formative approaches. Adapted from Vicente (1999) p. 133.

An analysis will be less efficient if it is not able to free it self from the existing solutions, because the analysis will inherit whatever deficiencies present in existing design (Vicente, 1999). This means that the analysis presented in this thesis will inherit the deficiencies of the present train driving task, but Burns & Hajdukiewicz (2004) argues that a work domain model is in a way a recreation of some of the steps behind the original design of the work domain. This idea can also apply to the formative approach as a whole. The formative analysis can, even if the goal of total device-independence is not attained, clarify some of the steps behind the original design. This can again help clarify the interdependence between the different components of the system and prove informative when altering existing technology, adding new or changing other parts of the system.

Device-independence was not achieved in this study. The value of describing a task device independent can be discussed. In the end, it is the modelling of the behaviour shaping constraints that make an analysis formative. Our study fulfils this demand, and the analysis can provide a recreation of some of the steps behind the present work solution. Our analysis can in this sense be device-dependent and escape some of the existing deficiencies.

### *4.2.2 Work as a Continuous Flow of Action*

The formative analysis applied here shows the train driving task as a string of separate subtasks, higher and lower strategies, social- organisation and cooperation, and worker competencies. The different subtasks and their subsequent paths is in reality a part of a continuous flow of action. One example is how the drivers are initiating the departure routine by checking the signal for permission to leave while approaching the station. Another is how they often give the conductor guard the permission granted signal and opens the doors simultaneously. This flow of action was illustrated by the OSDs (see appendix for examples).

The disintegrated presentation is a result of how the formative analysis models the task. Both Cognitive Systems Engineering (e.g Hollnagel, 2001; Hollnagel & Woods, 2005; Woods & Hollnagel, 2006) and Action Theory (Nardi, 1997; Norros, 2004) have discussed the pitfalls of a disintegrated view on work in action. What makes a formative analysis formative is the description of the behaviour shaping constraints, and the fragmentation of the task was necessary in order to show these. The results can despite of the disintegrated presentation of the flow of action be made clear by grounding the study in observations of work in context, and using techniques like the OSD.

### *4.2.3 Level of detail in the analysis*

This study was based on the CWA but did not go through with the whole analysis. The modelling tools and the design interventions are cut out of this application of the formative approach. The level of detail was from the beginning decided sacrificed for the broader picture of the relationship between the conceptual distinctions, and in order to be explorative.

However, where to set the actual level of detail when analysing the task proved difficult. Three examples will be discussed in the following.

First, this analysis presents some of the strategies present in the train driving task. They do not represent an exhaustive list of all of the available strategies because several strategies may be available (Vicente, 1999), and the scope of this study did not allow for such a detail. The ones presented here are largely the ones found in the existing organisation of work, and the results can as discussed earlier be described as descriptive. Second, this study was first and foremost conducted from the drivers' point of view, and this is important to take into consideration when evaluating the approach. This narrow perspective becomes especially evident in the analysis on the level of social- organisation and cooperation. The allocation of work is presented here, but the collaboration between the actors is not treated in a detailed way. Third, to decide the level of detail is also difficult on the level of worker competencies. This level is dealing with human capabilities and limitations, a category that deals with the whole field of psychology. Attention was however mentioned, as it is important in the monitoring strategy.

The problem of deciding the level of detail is linked to the choice of not applying any of the modelling tools suggested by the CWA. Despite these problems, this study has provided a description of how the constraints on the different conceptual distinctions influence each other and shape the task. This was exactly what we hoped to gain from applying this broad formative analysis. We can, in the spirit of the explorative nature of this study also interpret glitches in the analysis information about interesting areas for further investigation.

### *4.3 Further studies*

This study outlined how the constraints in the conceptual distinctions shaped the train driving task. The CWA (Vicente, 1999) suggests modelling tools associated with these conceptual distinctions, and these provide more detail. The result from these modelling tools could in further studies be presented in the framework suggested by this study, in order to further investigate how constraints shape the train driving task.

One of the aims of the formative approach is to support workers in dealing with context conditioned variability. The results show that this is an important feature of the train driving task. Devices like the IDU screen, and the DROPS centre, the Traffic Control Centre and the conductors are important in supporting the drivers in handling the context-conditioned variability. An interesting focus for further studies could be on how the organisation and devices aid the drivers in dealing with context- conditioned variability.

### *4.4 Conclusion*

This study applied a formative analysis of the train driving task. We have showed how the different constraints in five conceptual distinctions shaped the train driving task. The analysis also shed light on how the drivers deal with context-conditioned variability. The formative approach applied here thus proved itself useful for the analysis of train driving. Some problems were encountered. These were concerned with the ability to achieve complete device-independence, portray the work as a continuous flow of action, and difficulties of deciding on the level of detail. Nevertheless, the study provides an alternative starting point for a formative analysis by drawing a broader picture emphasising the interactions of the conceptual layer, and thereby contributes to Cognitive Engineering by offering a coherent framework for the presentation of the formative analysis.

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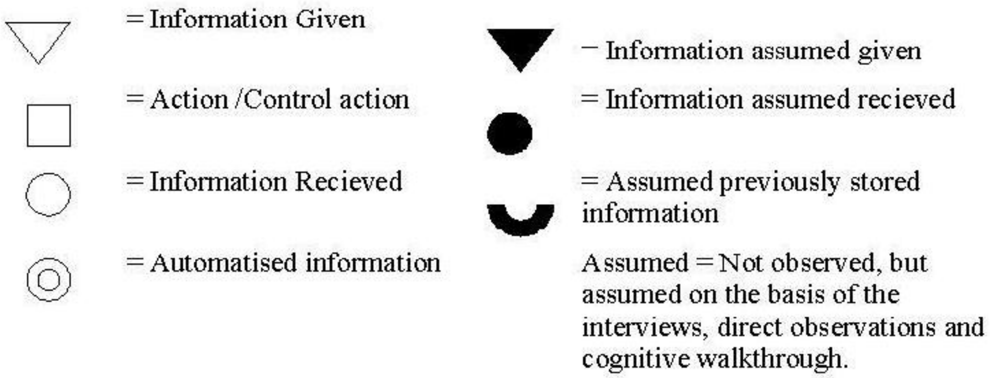
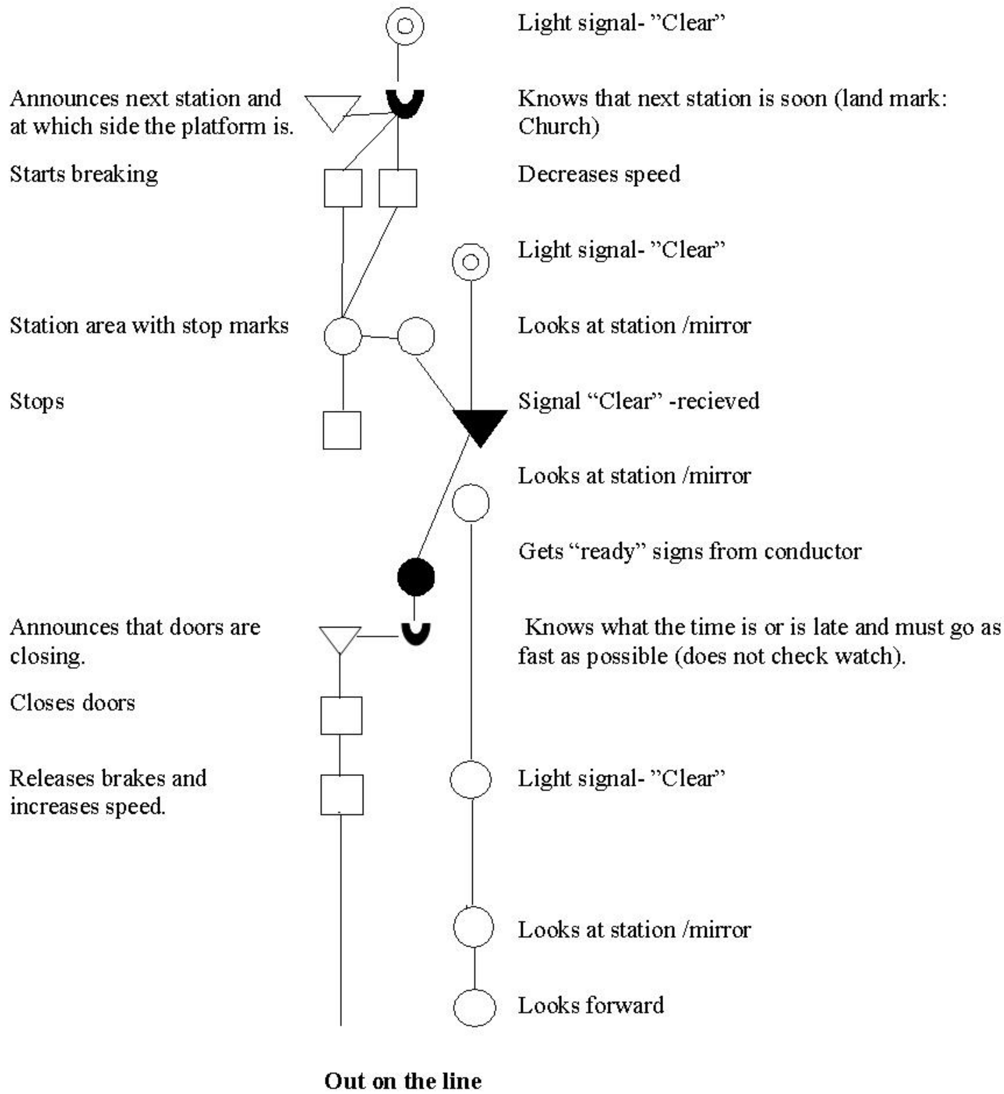
# Appendix

## Operational Sequence Diagrams (OSD) of Approaching & Leaving Station

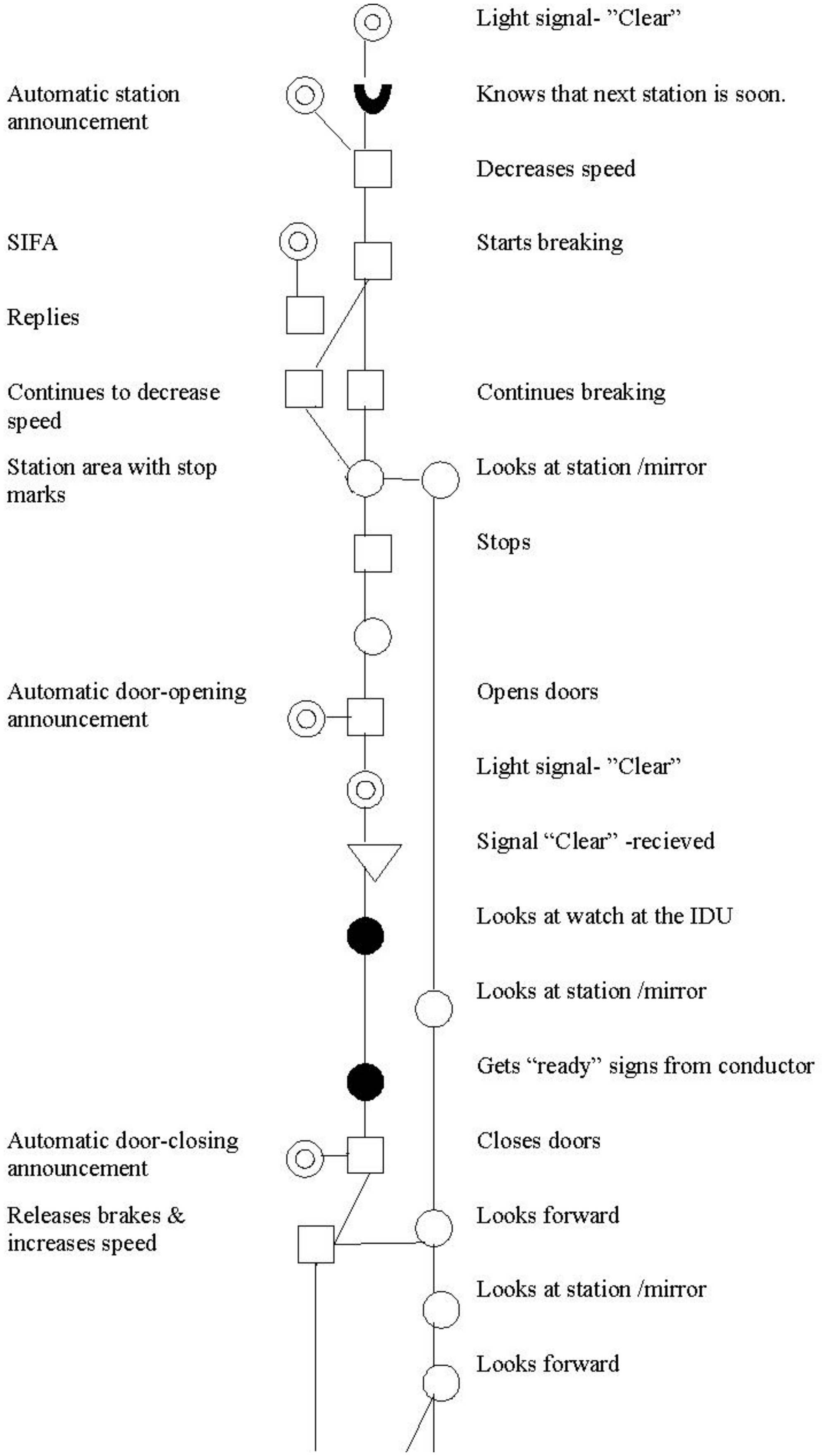
Explanation of symbols

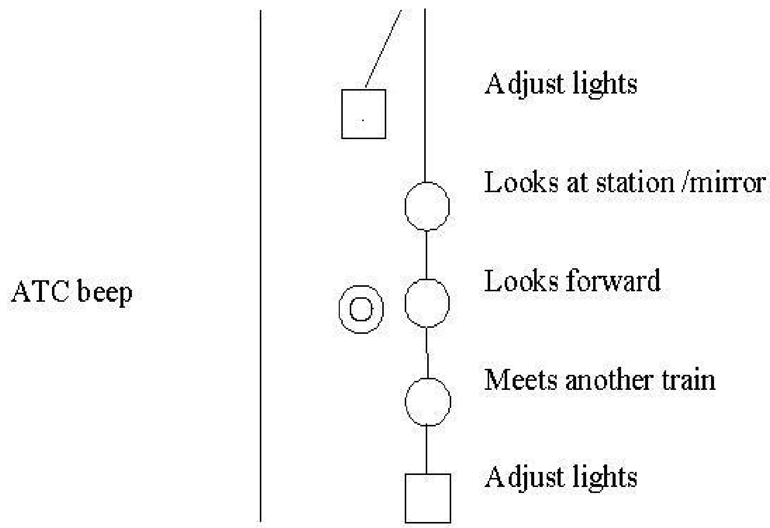



### Kolbotn Station – Type 69



**Kolbotn Station – Type 72**






**Out on the line**